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AN IN-HOME STUDY OF SUBJECTIVE RESPONSE TO SIMULATED SONIC BOOMS

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INTRODUCTION

The proposed development of a second-generation supersonic commercial transport has resulted in increased research efforts to provide an environmentally acceptable aircraft. One of the enviromental issues is the impact of sonic booms on people. Aircraft designers are attempting to design the transport to produce sonic boom signatures that will have minimum impact on the public. Current supersonic commercial aircraft produce an "N-wave" sonic boom pressure signature that is considered unacceptable by the public. This has resulted in first-generation supersonic transports being banned from flying supersonically over land in the United States, a severe economic constraint. By tailoring aircraft volume and lift distributions, designers hope to produce sonic boom signatures having specific shapes other than "N-wave" that may be more acceptable to the public and could possibly permit overland supersonic flight. As part of the effort to develop a second-generation supersonic commercial transport, Langley Research Center is conducting research to study people's subjective response to sonic booms. As part of that research, a system was developed for performing studies of the subjective response of people to the occurrence of simulated sonic booms in their homes.

The In-Home Noise Generation/Response System (IHONORS) provides a degree of situational realism not available in the laboratory and a degree of control over the noise exposure not found in community surveys. The computer-controlled audio system generates the simulated sonic booms, measures the noise levels, and records the subjects' ratings and can be placed and operated in individuals' homes for extended periods of time. The system was used to conduct an in-home study of subjective response to simulated sonic booms. The primary objective of the study was to determine the effect on annoyance of the number of sonic boom occurrences in a realistic environment.

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IN-HOME NOISE GENERATION/RESPONSE SYSTEM DIAGRAM

A diagram of the IHONORS system is shown in figure 1. The system consisted of a computer and compact disc player that played the simulated sonic booms at randomly-selected, pre-programmed times through a preamplifier and amplifier into three or four loudspeakers located in different rooms of the house. The two indoor microphones and sound level meters measured the levels of the booms as they occurred and also continuously measured the ambient noise levels in the home. The measurements were then transferred to the computer and stored on its hard disk. At the end of the day, the test subject used the trackball to answer a series of questions about his or her activities during the day and his or her subjective response to the sonic booms heard. Once a week the noise measurements and test subject responses were downloaded via a modem to a central computer. The data were then checked to ensure that the system was operating correctly.

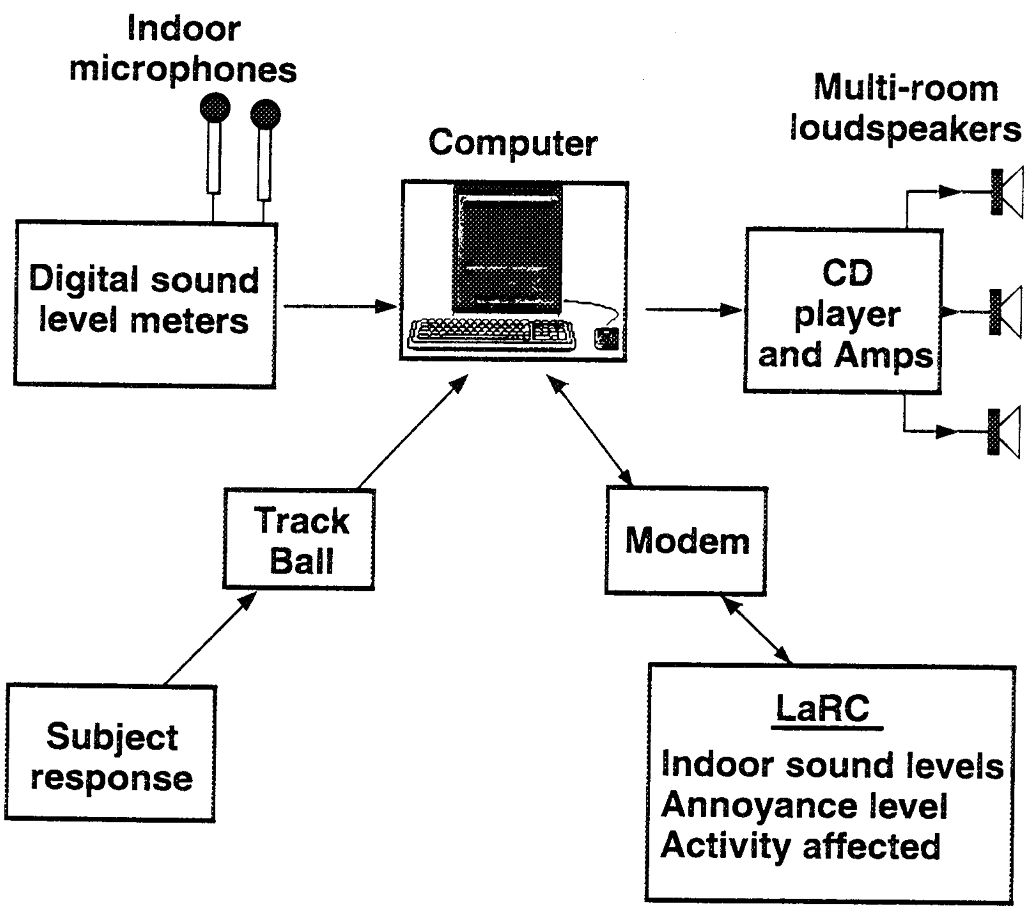


Figure 1.

DEPLOYED IN-HOME NOISE GENERATION/RESPONSE SYSTEM

Figure 2 shows the actual components as deployed in a test subject's home. Selected homes were limited to single family detached dwellings so that the simulated sonic booms would not penetrate the walls into neighbors homes as might be the case in apartments or townhouses. The range of homes selected covered the economic range from lower middle class to upper middle class. The computer, compact disc player, trackball, and monitor were placed on the shelves of a microwave oven cart. The preamplifier, amplifiers, and sound level meters were placed inside the lower cabinet of the cart. The cart was placed in a position that was convenient for the test subject and that simplified the installation of cables. Three or four loudspeakers were placed in the rooms that the test subject indicated he or she most used during the 14 hour boom period each day. The two microphones were placed in two of the rooms with loudspeakers. The system components blended in well with the existing decor in most cases and were often decorated with bric-a-brac by the test subject.

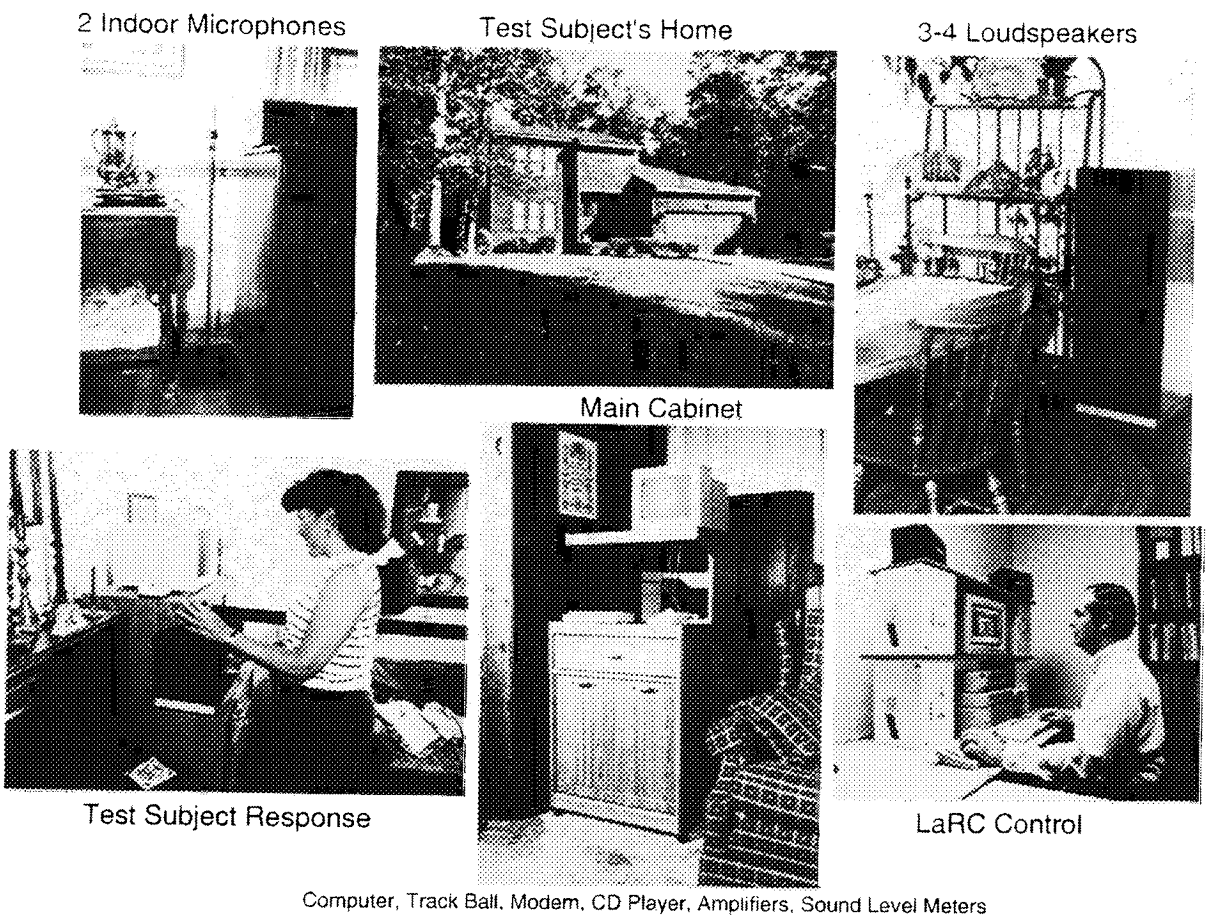


Figure 2.

TEST PLAN

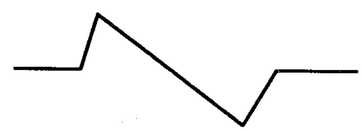
The final test plan is outlined in figure 3. Eight IHONORS systems were used to conduct the in-home study of subjective response to simulated sonic booms. A system was deployed for eight weeks in each of 33 homes. Each day the system played simulated sonic booms during a 14 hour period as the test subject went about his or her normal activities. At the end of the 14 hours the test subject rated his or her annoyance to the sonic booms heard during the day. A total of 264 weeks of data including over 1800 subjective annoyance responses to daily sonic boom exposures were collected, the equivalent of five years of sonic boom exposures in realistic environments.

- February 1993 to December 1993
- 33 homes
- 8 weeks per home
- 14 hour test day (no booms during normal sleep period)
- 1848 total exposure days
- 58,443 total sonic booms

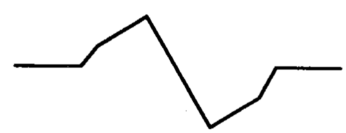
Figure 3.

As shown in figure 4, the sonic booms presented each day represented combinations of three sonic boom pressure signatures or waveforms, three A-weighted sound exposure levels (SEL(A)), and seven sonic boom frequencies. The SEL(A) levels used were nominally 66, 70, and 74 dB. These values covered the range of indoor sonic boom levels estimated for a variety of second-generation supersonic transport designs. The pressure waveforms represented an outdoor N-wave, an indoor N-wave, and an outdoor "shaped" wave. All the sonic booms had a rise time (τ) of four msec and a duration of 300 msec. The frequencies were 4, 10, 13, 25, 33, 44, and 63 booms per 14 hour period. Only one sonic boom waveform was presented each day. On most days the sonic boom was presented at only one SEL(A) level. On a few days the sonic boom was presented at two or three of the SEL(A) levels.

- 3 pressure signatures
    - outdoor N-wave, τ = 4 msec



    - indoor N-wave, τ = 4 msec
    - outdoor shaped, τ = 4 msec



- 3 levels - 66, 70, 74 dB - SEL(A)
- 7 boom occurrence rates - 4, 10, 13, 25, 33 ,44, 63 booms per day

Figure 4.

TEST SUBJECT RESPONSES

The information obtained from the test subjects is outlined in figure 5. The computer-generated questions answered by the test subject at the end of each day are summarized as follows: (1) when were you not inside your house, (2) what activities did you do while inside your house, (3) how annoying were the sonic booms you heard today on a 0 to 10 scale, and (4) were you startled by any of the sonic booms today? In addition to the daily questions, each test subject answered pre- and post-test questionnaires similar to those used in studies surveying people exposed to aircraft-generated sonic booms.

- Pre- and post-test questionnaires
- Daily computer-generated questions
  - When were you not inside the house?
  - What activities did you do while in the house?
  - How annoying were the sonic booms you heard today? (0 to 10)
  - Were you startled by any of the sonic booms today? (Yes or no)

Figure 5.

TEST DAY SUMMARY

The eight IHONORS systems were deployed in 33 test subjects' homes for a total of 1848 exposure days. Figure 6 gives a breakdown of how the test subjects responded during those 1848 days. Over 90 percent of the time, the subjects responded with an annoyance judgment. This was better than expected. Subjects were outside of the home for the entire 14 hour period only one percent of the time. Subjects were out of town or forgot to respond to the questions less than three percent of the time. Technical problems with the system caused the loss of data on less than six percent of the days. Although the systems were designed to and did recover by themselves from power outages by rebooting, the most common technical problem was a momentary brown-out or flicker in the power supply causing the computer to lose its default memory settings but not triggering a reboot of the system.

Type of day	Number	Percentage of total
Subject responded with annoyance judgment	1676	90.7 %
Subject was outside all day	19	1.0 %
Subject did not respond	47	2.6 %
Day voided due to technical problem	106	5.7 %
Total exposure days	1848	100 %

Figure 6.

EFFECT OF NUMBER OF SONIC BOOM OCCURRENCES ON ANNOYANCE

Figures 7 and 8 illustrate the preliminary results concerning the effect of number of booms heard. Figure 7 shows subjective annoyance ratings versus the SEL(A) level of the individual sonic boom repeated during the day. The number of occurrences (n) of the boom is divided into five intervals, each having roughly the same number of data points. The linear regression lines for each interval are plotted in the figure. As illustrated in the figure, the subjective annoyance response increases as the number of occurrences of a sonic boom increases.

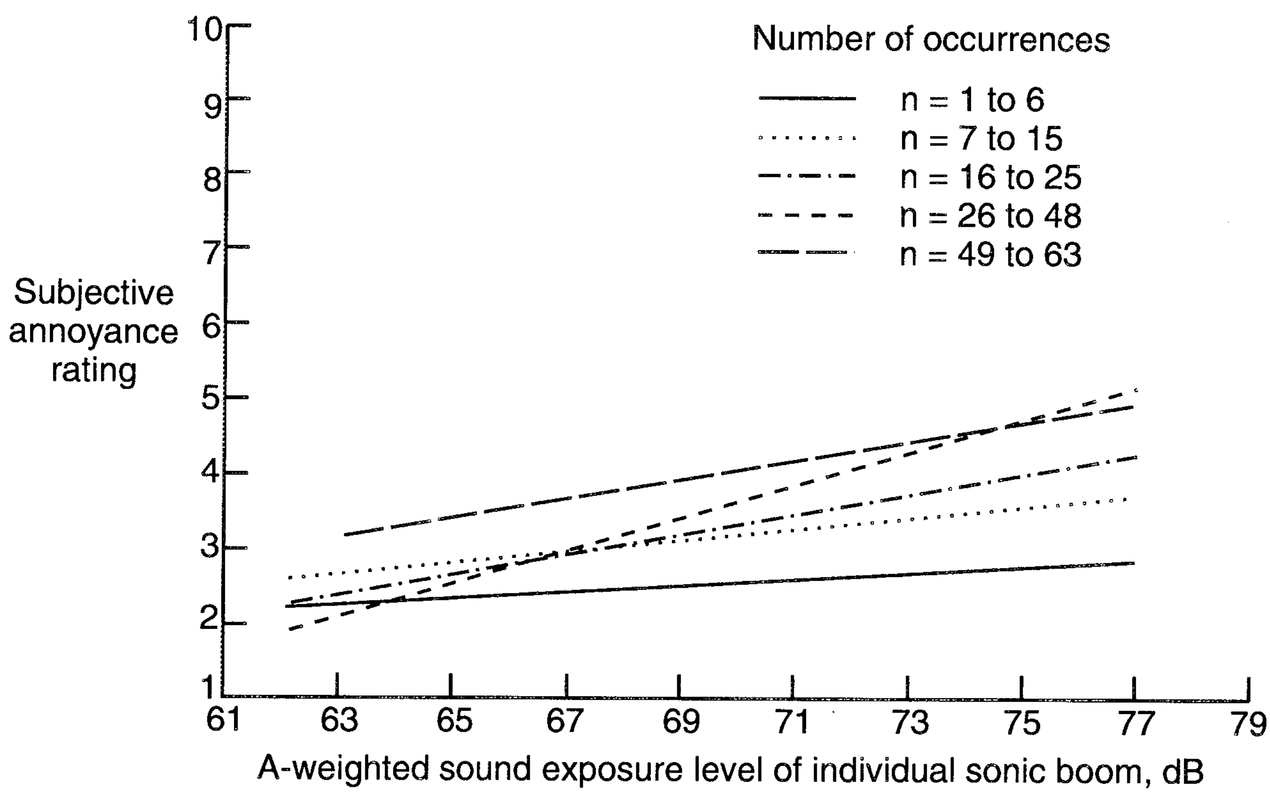


Figure 7.

This effect of number of occurrences can be modeled by the addition to the measured sonic boom level of the term *"k * log(number of occurrences)"*. Figure 8 shows the values of *"k"* and the corresponding 95% confidence intervals determined from regression analyses for each of several noise metrics. The metrics were perceived level (PL), two versions of Zwicker's loudness level (LL_Zd and LL_Zf), perceived noise level (PNL), A-weighted sound exposure level (SEL(A)), C-weighted sound exposure level (SEL(C)), and unweighted sound exposure level (SEL(U)). The metrics represent different ways of modeling the frequency response of the ear (refs. 1,2). As shown in figure 8, analyses of the data indicate that the calculated value of *"k"* ranged from 10 to 15 depending on the noise metric considered. However, for almost all the metrics, the 95% confidence interval about the calculated value includes the value of 10. Therefore, in those cases, the value of *"k"* cannot, statistically, be said to be significantly different from 10, the predicted value based on energy addition.

The two metrics whose 95% confidence intervals on *"k"* did not include the value of 10 were examined further. The value of *"k"* was calculated from the regression coefficients a_1 and a_2 for each metric. Comparison of a_2, the *"log(number of occurrences)"* coefficient, across all metrics found that the value of a_2 was constant across all metrics, indicating that the differences in *"k"* for SEL(U) and SEL(C) were due to the metric and not the effect of number of occurrences.

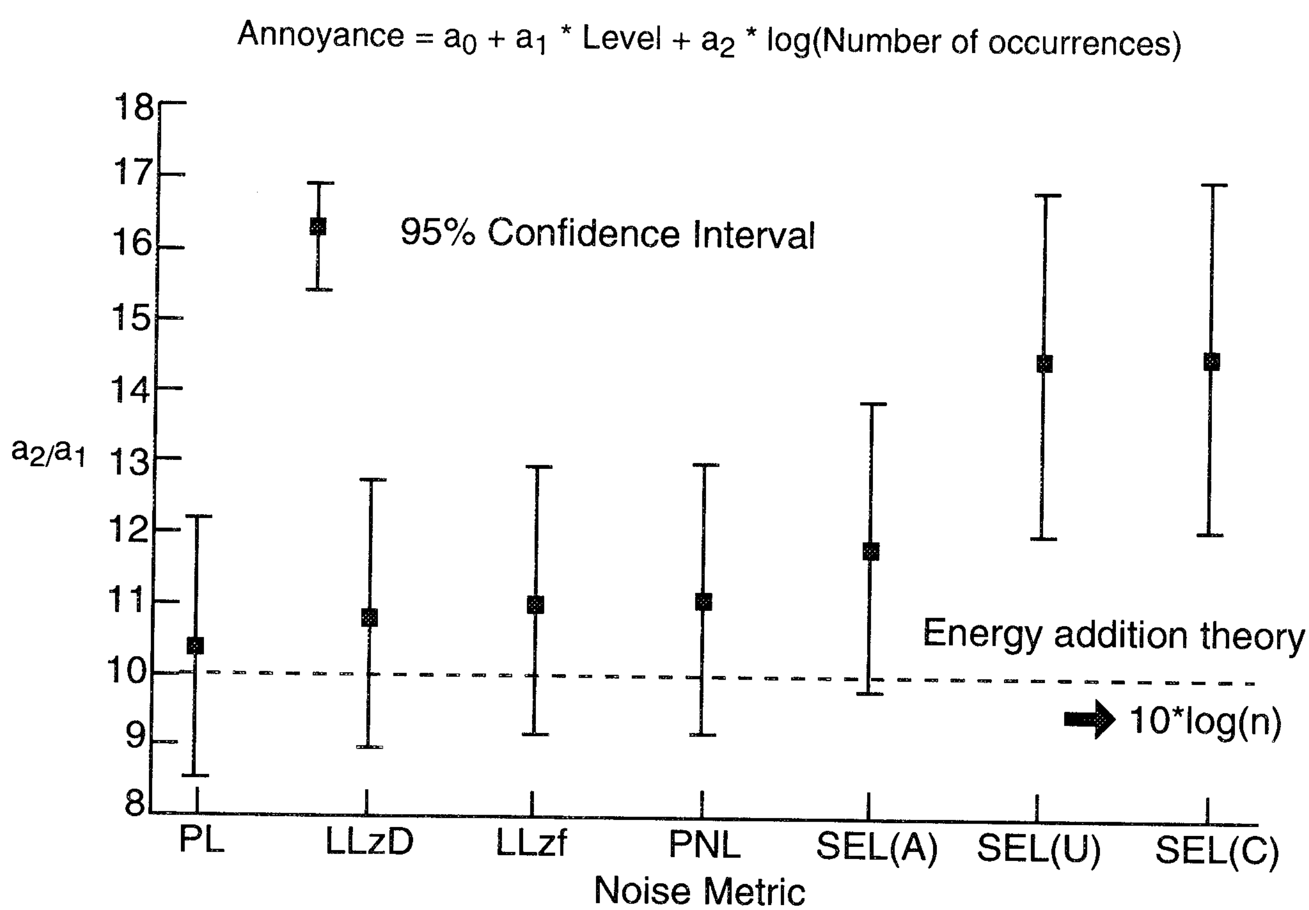


Figure 8.

Having confirmed the model for summing the effect of multiple sonic booms, the total daily sonic boom exposure was calculated in terms of each of the noise metrics for comparison with the test subjects' daily annoyance judgments. Daily exposure is commonly expressed in terms of Day-Night Level (DNL). Day-Night Level uses "10*log(number of occurrences)" to sum multiple events and then averages the noise energy across 24 hours (ref. 2). (No late night penalties were assessed.) Although DNL is usually associated with A-weighted sound pressure level, for the purpose of this study, a DNL was calculated using each of the noise metrics.

The predictive ability of the noise metrics was then compared based on the correlation coefficients between the subjective annoyance ratings and the different DNL's. The resulting rank order of metrics is shown in figure 9. Perceived level was the best predictor of annoyance to the simulated sonic booms. Figure 9 also illustrates the subjective annoyance ratings as a function of DNL(PL) and as a function of the more commonly used DNL(A) and DNL(C). A best-fit regression line is drawn through the data in each plot.

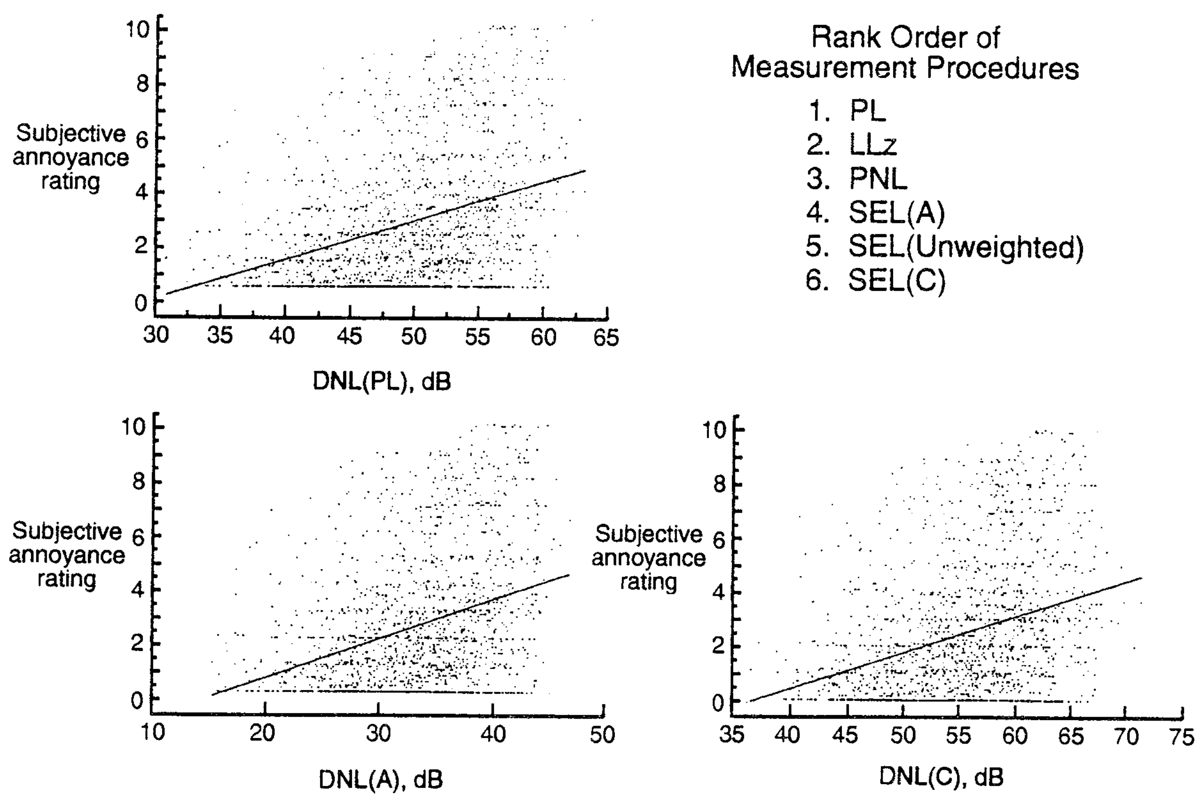


Figure 9.

Figure 10 shows the effect of sonic boom waveform on annoyance for noise measurements based on perceived level. The figure shows the regression line of subjective annoyance rating on day-night level based on perceived level for each of the three sonic boom waveforms used in the study. Indicator (dummy) variable analyses found no difference in either slope or intercept between the three different sonic boom waveforms. This result was the same for all the noise metrics considered.

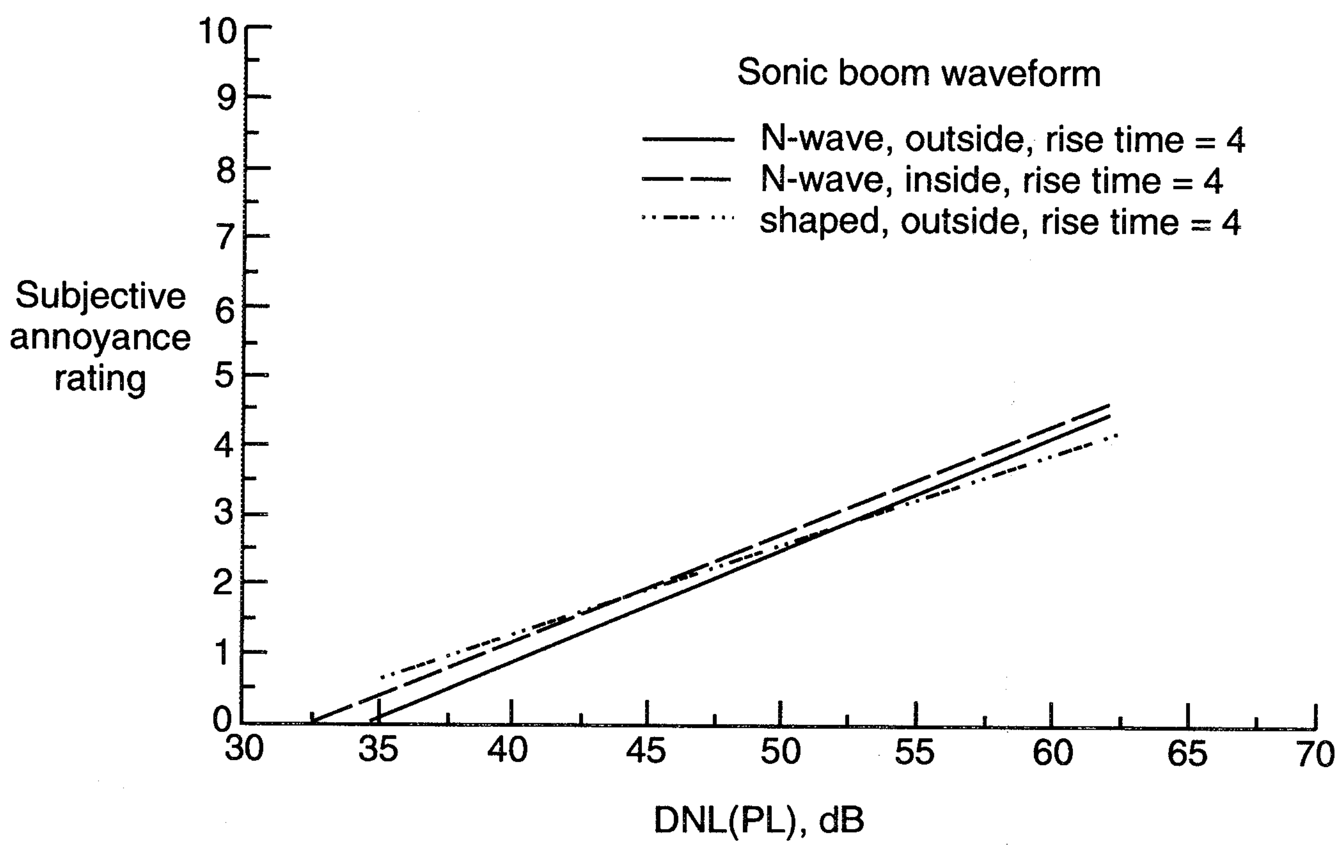


Figure 10.

Figure 11 shows the effect of startle on annoyance for noise measurements based on perceived level. The regression lines for both startled and not startled are shown for subjective annoyance rating plotted against day-night level based on perceived level. Indicator (dummy) variable analyses indicated a significant difference in both slope and intercept between startled and not startled by a sonic boom. Annoyance is greater when the test subject is startled and the magnitude of the increase in annoyance increases as the sonic boom exposure increases. This effect was the same for all the noise metrics considered.

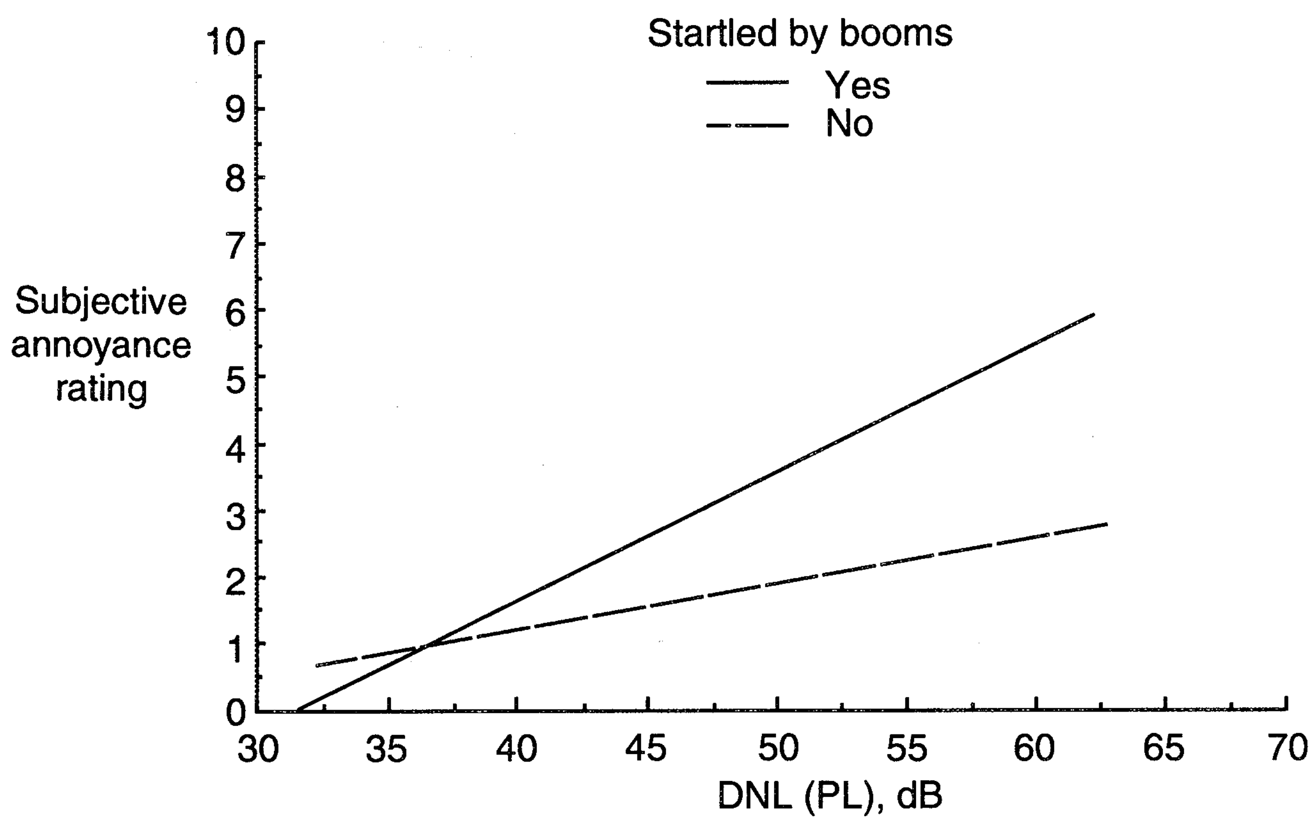


Figure 11.

PERCENTAGE OF TEST SUBJECTS HIGHLY ANNOYED AS A FUNCTION OF A-WEIGHTED DAY-NIGHT LEVEL

The impact of aircraft flyover noise has usually been examined in terms of the percent of people highly annoyed versus the outdoor A-weighted day night level. Figure 12 illustrates this dose-response relationship for the results from this study. A subjective response rating greater than seven was considered a highly annoyed response. The circles in the plot represent the results of this study using the measured indoor levels. The shaded area represents the range of data when the indoor levels are transformed to outdoor levels by the addition of a 15 to 20 dB correction for house attenuation (ref. 3). Comparison of the sonic boom data with the Federal Aviation Administration (FAA) guideline (Shultz curve, ref. 4) indicates that a greater percentage of the test subjects were highly annoyed by the simulated sonic booms than would be expected for aircraft flyover noise at a given level.

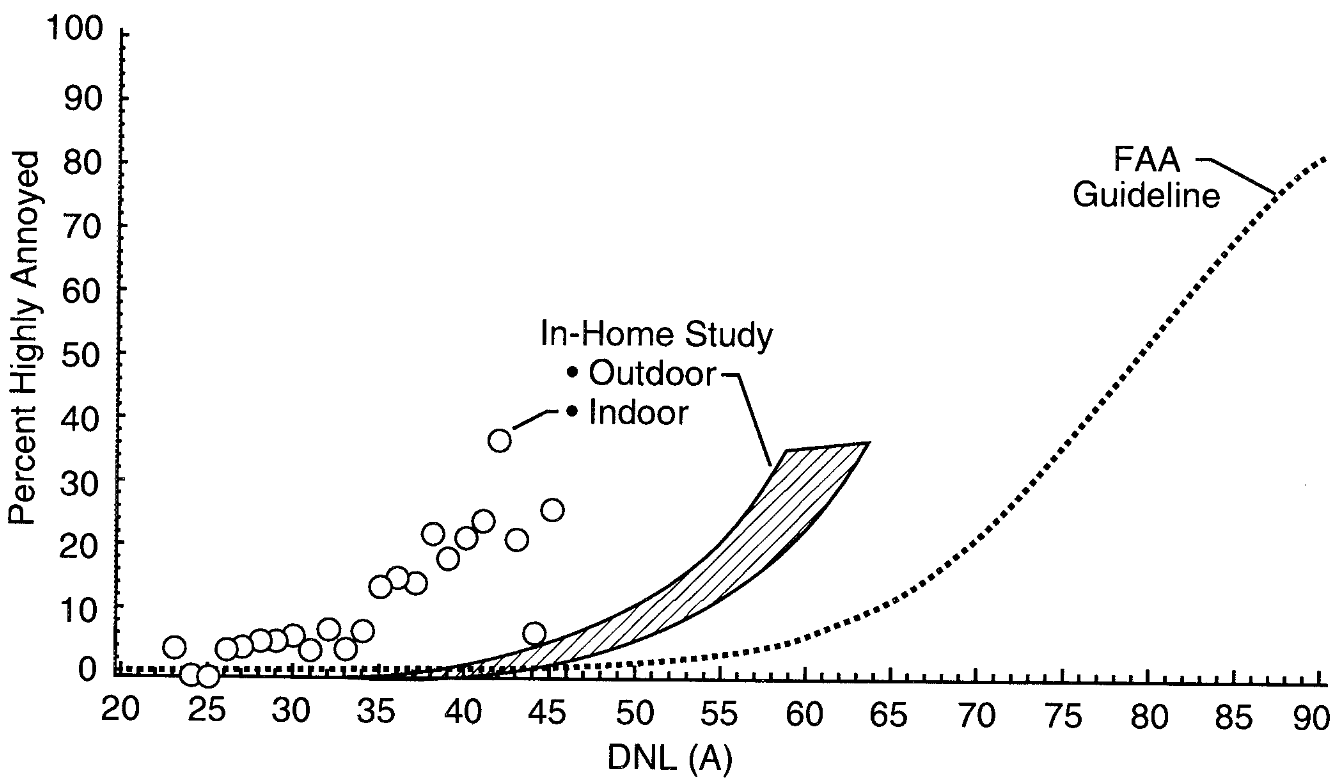


Figure 12.

PERCENTAGE OF TEST SUBJECTS HIGHLY ANNOYED AS A FUNCTION OF C-WEIGHTED DAY-NIGHT LEVEL

The impact of impulse noise has usually been examined in terms of the percent of people highly annoyed versus the outdoor C-weighted day night level. Figure 13 illustrates this dose-response relationship for the results from this study. A subjective response rating greater than seven was considered a highly annoyed response. The circles in the plot represent the results of this study using the measured indoor levels. The shaded area represents the range of data when the indoor levels are transformed to outdoor levels by the addition of a 15 to 20 dB correction for house attenuation (ref. 3). Comparison of the sonic boom data with the Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) recommended curve (ref. 5) indicates that a smaller percentage of the test subjects were highly annoyed by the simulated sonic booms than would be expected by other impulse noises at a given level.

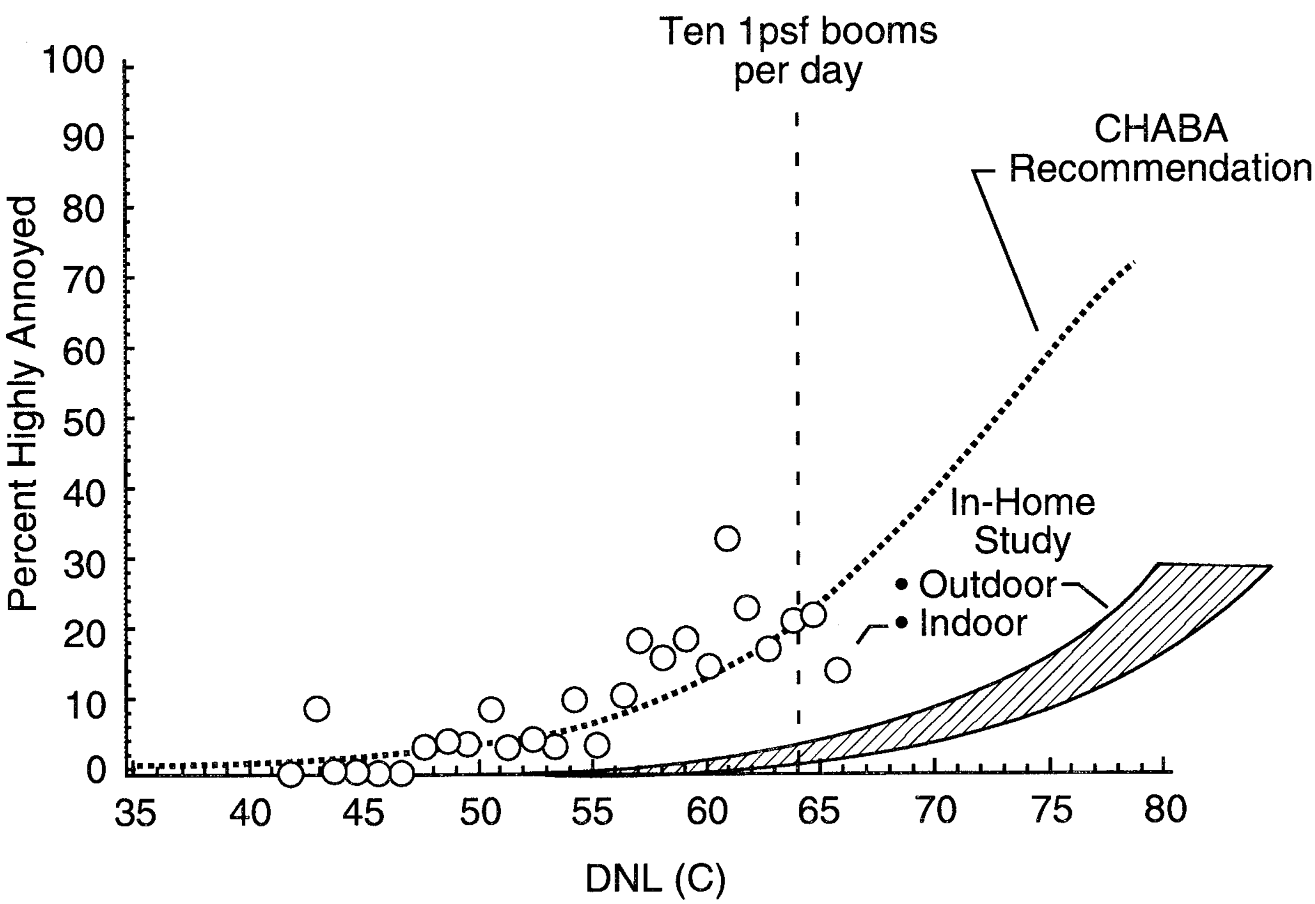


Figure 13.

CONCLUSIONS

Figure 14 summarizes the conclusions reached so far from the in-home study of subjective response to simulated sonic booms.

- Proven, reliable system for in-home testing
- In-home testing requires large resource commitment
- "Level + 10 * log(n)" confirmed for multiple occurrences
- Perceived level was best annoyance predictor
- Startle increases annoyance

Figure 14.

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